THE CRASH AND FIELD PERFORMANCE OF SIDE-MOUNTED AIRBAG SYSTEMS

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ABSTRACT

Drawing on recent Canadian field collision investigations and crash testing using the SIDIIs dummy, the field experience and crash performance of side-mounted airbag systems are reviewed. All of the inflatable technologies tested demonstrated the ability to greatly reduce head injury potential. Further improvements to the design of inflatable head protection devices are required to better ensure they contain and protect the head of occupants seated in locations forward of the mid seat track. New moving deformable barrier designs, such as the one recently developed by the IIHS, appear to offer significant advantages over designs currently used to regulate side impact protection. Improving the level of protection against chest injury to car occupants in SUV-to-car side impacts represents a significant challenge.

INTRODUCTION

The past 15 years have seen a number of regulatory initiatives in both the US and in Europe in the area of side impact testing. To gain an appreciation of the relative merits and limitations of these initiatives, Transport Canada initiated a major crash testing programme in 1988. To date, over 80 side impact crash tests have been carried out as part of this programme. Earlier portions of this testing programme were directed at: assessing the appropriateness of the moving deformable barriers (MDB) and test procedures developed in the US and Europe [1], generating comparative dummy response data using the EuroSID 1, BioSID and the US SID [2], as well as identifying opportunities to improve side impact protection either through the use of innovative padding schemes or other emerging technologies such as side-mounted airbag systems [3]. In 1993, Transport Canada initiated a directed field collision study of vehicle-to-vehicle side impacts. The main purpose of the study is to generate a large in-depth database of side impacts where the collision circumstances match those simulated by US and European side impact testing procedures. In addition to providing data on the

nature of the Canadian side impact problem in far greater detail than available through police-generated databases, this directed study offers a pool of collision cases for reconstruction. Several such reconstructions have already been performed and have been reported upon elsewhere[4].

Transport Canada is now reexamining the relevance of existing side impact testing practices in light of the changing nature of the side impact collision problem in Canada. Of particular concern are the implications of the changing composition of the Canadian vehicle fleet, particularly with respect to the growing representation of multi-purpose passenger vehicles (MPV) in the form of light trucks, vans, and sport utility vehicles. A recent analysis of the directed study of side impacts (DSSI) revealed that of the passenger car occupants injured at the AIS 3 or greater level, 67% sustained their injuries in impacts where the striking vehicle was an MPV. The same data also indicated the need to explore the use of dummy sizes other than the 50th percentile male in future Canadian regulations. Female occupants were observed to be over-represented among seriously injured occupants, accounting for just over 60 % of the DSSI sample with an injury rating of MAIS 3 or greater [4].

Another significant development in side impact safety in recent years is that of side airbag systems. These are being introduced, either as standard or as optional equipment, in a steadily increasing number of vehicle models. In response to this development, Transport Canada's side impact protection programme was broadened to include both in-position and out-of-position (OOP) testing of side airbag systems using a variety of child dummies. This led to the development of a number of testing protocols to assess potential injury risk to children from side airbags [5]. The OOP testing procedures developed by Transport Canada were subsequently incorporated into a broader set of recommended testing procedures developed by the Side Airbag Out-of-Position Injury Technical Working Group chaired by the Insurance Institute for Highway Safety (IIHS)

Table 1.
SIDIIs Driver Test Matrix

Test Vehicle	Driver Side Airbag	Bullet Vehicle
Audi A6 (TC00-208)	Curtain & Torso (SM)	Explorer (50 km/h; 27 Degrees)
Audi A6 (TC99-233)	Torso(SM)	US MDB (54 km/h; 27 Degrees)
BMW 323i (TC99-231)	Tube & Torso (DM)	Camry (50 km/h; 0 Degrees)
BMW 323i (TC99-232)	Tube & Torso (DM)	Explorer (50 km/h; 0 Degrees)
Volvo C70 (TC00-210)	Head & Torso (SM)	Explorer (45 km/h; 0 Degrees)
Volvo S80 (TC00-217)	Curtain & Torso (SM)	Explorer (45 km/h; 0 Degrees)
Volvo S80 (TC99-235)	Curtain & Torso (SM)	Explorer (50 km/h; 0 Degrees)
SAAB 9-3 (TC99-225)	Head & Torso (SM)	Camry (50 km/h; 0 Degrees)
SAAB 9-3 (TC99-223)	Head & Torso (SM)	Explorer (50 km/h; 0 Degrees)
SAAB 9-3 (TC99-224)	Head & Torso (SM) / Suppressed	Explorer (50 km/h; 0 Degrees)
Toyota Camry (TC99-227)	None Fitted	Camry (50 km/h; 0 Degrees)
Toyota Camry (TC99-257)	Torso(SM)	Camry (50 km/h; 0 Degrees)
Toyota Camry (TC99-259)	Torso(SM)	Camry (54 km/h; 27 Degrees)
Toyota Camry (TC99-228)	None Fitted	Explorer (50 km/h; 0 Degrees)
Toyota Camry (TC99-258)	Torso(SM)	Explorer (50 km/h; 0 Degrees)
Toyota Camry (TC98-217)	None Fitted	Explorer (50 km/h; 27 Degrees)
Toyota Camry (TC99-254)	None Fitted	Explorer (54 km/h; 27 Degrees)
Toyota Camry (TC99-226)	None Fitted	EEVC MDB (50 km/h; 0 Degrees)
Toyota Camry (TC99-241)	None Fitted	US MDB (54 km/h; 27 Degrees)
Toyota Camry (TC00-209)	None Fitted	IIHS V1 MDB (50 km/h; 0 Degrees)
Toyota Camry (TC01-201)	None Fitted	IIHS V1 MDB (54 km/h; 27 Degrees)
Toyota Corolla (TC99-252)	None Fitted	US MDB (54 km/h; 27 Degrees)
Toyota Corolla (TC99-249)	Torso(SM)	US MDB (54 km/h; 27 Degrees)
Ford Windstar (TC00-212)	None Fitted	Explorer (45 km/h; 0 Degrees)
Cadillac de Ville (TC00-201)	Torso(SM)	Explorer (50 km/h; 27 Degrees)
Mercury Cougar (TC99-253)	Head & Torso (SM)	Explorer (50 km/h; 0 Degrees)

[6]. These testing procedures and associated performance requirements have been incorporated in a Memorandum of Understanding (MOU) governing side impact protection between vehicle manufacturers and Transport Canada.

The preliminary findings of Transport Canada's In-Position (IP) side airbag test programme, based on static deployments, are being presented in a separate paper at this conference [7].

TC CRASH TESTING PROGRAMME

Over the past two years, over 30 full scale vehicle side crash tests have been conducted by Transport Canada. Two fully instrumented side impact dummies were used in each of these tests, one positioned in the driver's seat, the other in the rear left passenger position. The three combinations of crash test dummies employed in the tests performed to date are as follows:

- BioSID driver / SIDIIs passenger (6 tests);
- SIDIIs driver / SIDIIs passenger (21 tests); and
- SIDIIs driver / TNO Q3 passenger (5 tests).

The six tests employing the BioSID/SIDIIs dummy combination were performed as part of an on-going joint research project between Transport Canada and the Australian Department of Transport and Regional Services to examine the effects of mass, stiffness and geometry on injury outcome in side crashes. Some preliminary findings generated from the Australian portion of this test series have already been published [8].

The remaining 26 crash tests employed SIDIIs dummies in the driver position accompanied by either another SIDIIs or a TNO Q3 3-year old dummy in the rear. The choice of the SIDIIs, for much of the testing was motivated by the biofidelity

of the dummy, the high representation of females observed in the field collision data, and because this dummy serves as a surrogate for both a small female as well as an adolescent child.

The choice of the TNO Q3 dummy was motivated largely because the dummy was designed for use in both frontal and side impacts, and is the only child dummy currently capable of measuring lateral chest compression.

For the subset of 26 tests employing the SIDIIs in the driver position, two vehicle models and three moving deformable barriers were used as striking vehicles. The two vehicle models were the Toyota Camry (4-door) and the Ford Explorer (4-door, 4x4).
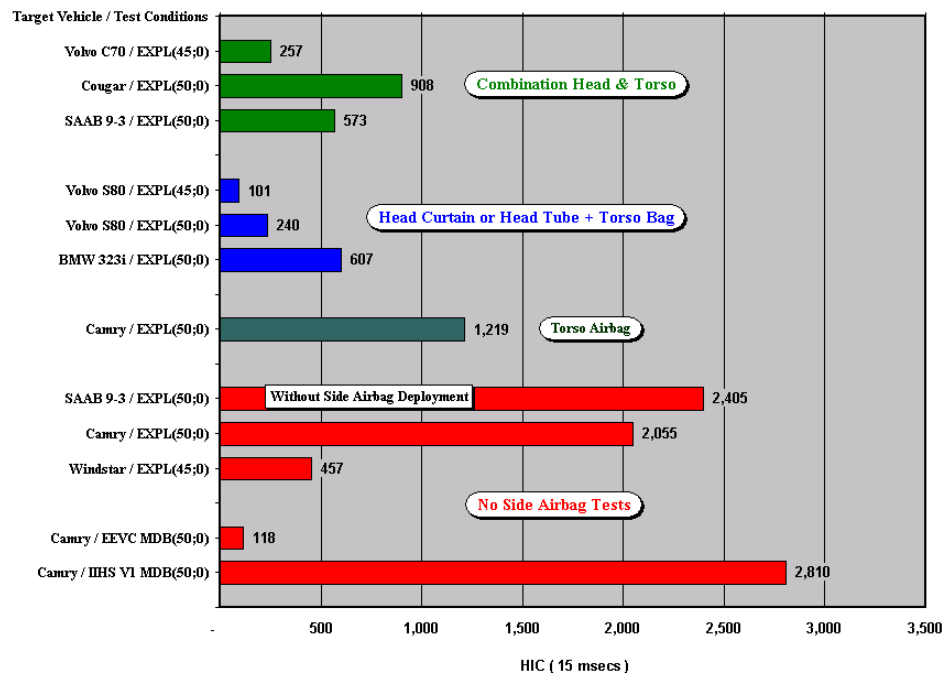

Figure 1. Peak Driver (SIDIIs) HIC Values Recorded In Perpendicular Explorer and MDB Tests
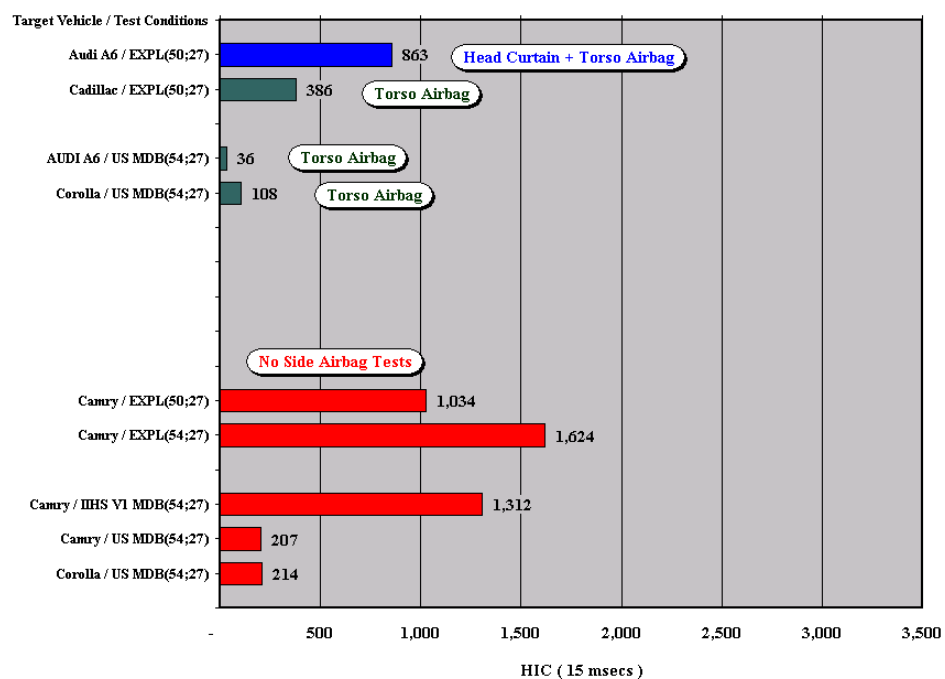

Figure 2. Peak Driver (SIDIIs) HIC Values In Crabbed Explorer and MDB Tests

The barriers employed consisted of EEVC MDB, the US MDB and the IIHS MDB (prototype).

The Toyota Camry was chosen to represent a typical mid-sized passenger car, and the Ford Explorer to represent a typical mid-sized SUV. Both vehicles were used as bullet vehicles in crabbed and non-crabbed alignments. All crabbed tests were performed with the wheels angled at 27 degrees. Alignment of the bullet vehicle with the target vehicle followed US testing protocols in the crabbed tests, while the non-crabbed (i.e. perpendicular) tests were performed following ECE testing protocols. In the case of the Ford Explorer bullet tests, crabbed tests were conducted with the vehicle impacting the target vehicle at either 50 km/h or 54 km/h. Non-crabbed test were performed at either 45 km/h or 50 km/h. In the case of the Camry bullet tests, the impact speed was 54 km/h in the crabbed tests, and 50 km/h in the non-crabbed tests. The EEVC MBD tests were all run at 50 km/h (non-crabbed); the US MDB tests were all run at 54 km/h.

Two MDB-to-vehicle tests were also performed using a prototype MDB developed by IIHS to mimic the front-end geometry and ground clearance of typical SUVs and pickup trucks. The design of this MDB is based on the FMVS 214 barrier, but is contoured to more closely represent the front of an SUV, with the top edge of the barrier being 200 mm higher relative to the ground. This in part reflects the increased height of the barrier face itself (+100 mm), and the increased ground clearance (+100 mm). In the initial tests by Transport Canada using this barrier face, the MDB was ballasted to achieve a total mass of 1,500 kg. This MDB variation was used both in a perpendicular impact conducted at 50 km/h and in a crabbed test at 54 km/h. In both cases the target vehicle was a late model Toyota Camry.

The SIDIIs driver tests were conducted with the front seat positioned either in the foremost seat track position or a position rearward of the foremost position. In the case of the latter, the horizontal (fore-aft) seat track position was obtained drawing on geometrical relationships from the ATD Position Model (ATDPM) developed by the University of Michigan Transportation Research Institute (UMTRI) to establish the typical position of a small female driver [9].

SIDIIs Driver Test Results

One of the primary objectives of the initial series of tests conducted by Transport Canada was to examine the upper limits of side protection achievable with side airbag systems, particularly with respect to head protection in vehicle-to-vehicle impacts where the striking vehicle is an MPV with an elevated hood line. The SIDIIs driver Head Injury Criterion (15 ms) values observed in the subset of tests in which the target vehicle was impacted by a Ford Explorer in a straight perpendicular impact (10 tests) are summarized in Figure 1. For comparative purposes, the corresponding results obtained with the EEVC MDB and the IIHS MDB in perpendicular tests of one of the target vehicle models, the Toyota Camry, are also included in Figure 1. The same findings for the series of tests where the bullet vehicle was run in a crabbed mode are summarized in Figure 2.

Two tests were performed to establish the baseline level of head injury risk in a pure perpendicular SUV-to-car side impact at 50 km/h. The vehicle models tested for this purpose were a Toyota Camry not fitted with any side airbag, and a SAAB 9-3 with the side airbag system deactivated. Driver head contact with the hood of the striking Ford Explorer was observed in both tests. The peak resultant head acceleration observed in the Camry test was 230 g with an associated HIC of 2,055. The SAAB-3 test produced nearly identical results, a peak resultant head acceleration of 258 g with an associated HIC of 2,405.

A total of five vehicle models fitted with side airbag systems incorporating head protection were impacted by the Ford Explorer in straight perpendicular tests. The vehicle models tested included the Volvo C70, the Mercury Cougar, and the SAAB 9-3, all fitted with seat-mounted combination head and torso side airbags. Also tested was the BMW 323i equipped with a head tube and door-mounted torso bag, and the Volvo S80 equipped with a head curtain and seat-mounted torso airbag. The latter vehicle model was tested twice, once at 50 km/h and once at 45 km/h.

In comparison to the baseline tests, all of the head responses observed in this series of six tests were low. The driver HIC values ranged from a low of 101 to a high of 908. The peak driver resultant head acceleration values were all below 100 g. Head contact with the intruding hood of the Explorer was prevented in all three tests involving seat-mounted combination head and torso side airbags. In each of these tests, deployment of the combination airbag was achieved very early in the collision event and containment of the head was sustained through the dummy loading phase.

In the case of the SAAB 9-3, which was tested both with and without activation of the side airbag, the added head protection afforded by the side head

and torso airbag was clearly evident. A comparison of the driver head responses observed in these two tests is depicted in Figure 3. With deployment, the peak acceleration was reduced from 258 g to 81 g the
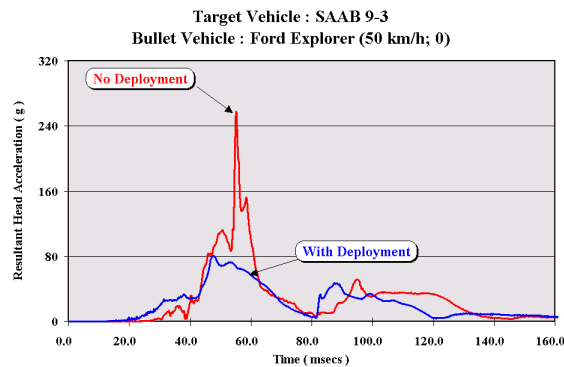

Figure 3. Head Accelerations (SAAB 9-3 Test)

associated HIC values were reduced from 2,405 to 573 respectively.

The degree of head containment achieved in tests of side airbag systems with separate head protection systems was very limited. In the BMW 323i test there was very limited engagement of the head with the head tube. During the loading event sufficient lateral bending of the neck and torso occurred to allow the head to slip under the tube after initial contact. Similarly, there was negligible engagement of the head/neck complex with the deploying head curtain in both of the Volvo S80 tests. The present design of the curtain does not extend forward enough to engage the head if the occupant is seated well forward of the mid seat track, as was the case in both of the SIDIIs tests. In the BMW test, as well as in the two Volvo tests, the lack of direct head contact with the intruding side structure and/or hood of the Explorer is likely attributable to the torso airbags. In both vehicles, deployment occurred early and the coverage provided by the torso bags extended to the shoulder complex. As a result, there was limited rotation of the upper torso relative to the side door structure. In the Volvo tests, the head/neck complex engaged the top of the torso bag during the latter portion of the loading event. This may also have aided in avoiding direct head contact.

As part of the above SUV-to-car test series, a Toyota Camry fitted with only a seat-mounted torso airbag was also tested. Direct driver head contact was observed in this test, although the intensity of the head impact, as measured by HIC, was greatly reduced relative to the baseline Camry test (1,219 vs. 2,055).

The Toyota Camry was also subjected to two perpendicular 50 km/h MDB tests, one with the EEVC barrier and one with the IIHS barrier. As the EEVC barrier was designed to represent a typical passenger car, owing to the absence of direct head contact, the test produced a relatively low driver HIC value (118). The test with the IIHS barrier produced direct contact of the driver's head with the barrier face. Despite the reduced mass of the barrier (1,500 kg), the test yielded a HIC value greater than that observed in the Explorer-to-Camry test (2,810 vs. 2,055) performed under nominally the same test conditions. A comparison of the driver head responses observed in the IIHS test and the Explorer test is presented in Figure 4. Although head contact occurred earlier in the barrier the difference in timing was not significant.
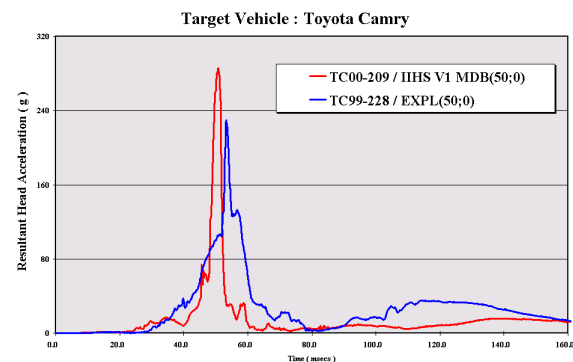

Figure 4. Explorer Test vs. IIHS-TC MDB Test

If one compares the findings presented in Figures 1 and 2, it can be observed that tests where the bullet vehicle was crabbed generally produced low HIC values in comparison with perpendicular impact tests. The test matrix was constructed to allow the effects of crabbing to be quantified under a variety of different test conditions. The influence of crabbing the bullet vehicle on driver HIC values is summarized in Figure 5. All three comparisons are based on the driver head responses obtained in tests of the Toyota Camry. Note that the target Camry models used in the Camry-to-Camry tests were equipped with torso airbags, while those in the Explorer-to-Camry tests and the IIHS MDB-to-Camry tests were not equipped with torso bags. As can be observed all of the crabbed tests produced significantly lower driver HIC values under similar test conditions (54 km/h crabbed test vs. 50 km/h perpendicular tests).

From the results presented in Figure 5, it can be further observed that the crabbed IIHS MDB test produced a driver HIC value, which although lower,
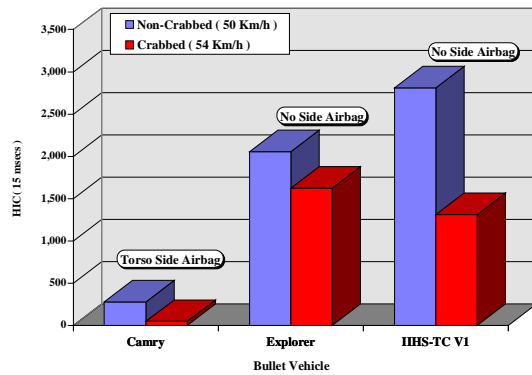
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Figure 5. Influence of Crabbing on HIC Values

is reasonably comparable to that recorded in the crabbed Explorer test (1,312 vs. 1,624).

The peak SIDIIs driver rib reflection values observed in the subset of tests in which the target vehicle was impacted by either a Ford Explorer or a MDB in a straight perpendicular impact are summarized in Figure 6. The corresponding data for tests where the bullet vehicle was crabbed are summarized in Figure 7.

With the exception of the SAAB 9-3, all of the vehicle models subjected to perpendicular impacts with the Ford Explorer showed relatively elevated peak thoracic rib deflection values, with one or more rib deflection exceeding 50 mm. This was true even when the impact speed was reduced from 50 km/h to 45 km/h. The elevated load paths produced in these

tests resulted in significant interior compartment intrusion at the height of the driver's chest (~500 mm). This is clearly reflected in the chest response values.

The peak driver thoracic deflection values observed in tests where the Explorer was crabbed were typically lower, ranging from 37.9 mm to 49.2 mm. However, this in part can be attributed to the fact that three of the four crabbed tests were performed at 50 km/h rather than 54 km/h. The influence of crabbing can be best appreciated by comparing the peak thoracic deflection values observed in the test. These results are presented in Figure 8.

From the results presented in Figure 8, it can be seen that the peak driver thoracic deflections observed in the crabbed tests conducted at 54 km/h were consistently lower than those observed in the perpendicular tests conducted at 50 km/h. However the differences are clearly less pronounced than those associated with the HIC values. The results also highlight the extent to which thoracic injury risk is elevated in SUV-to-car impacts in comparison to car-to-car impacts. In this respect it is also worthwhile to note that, although the peak deflection values observed in tests with the IIHS MDB were consistently lower than those produced in the Explorer tests, they nevertheless are approximately twice as high as those produced with MDBs currently used in side impact regulations.
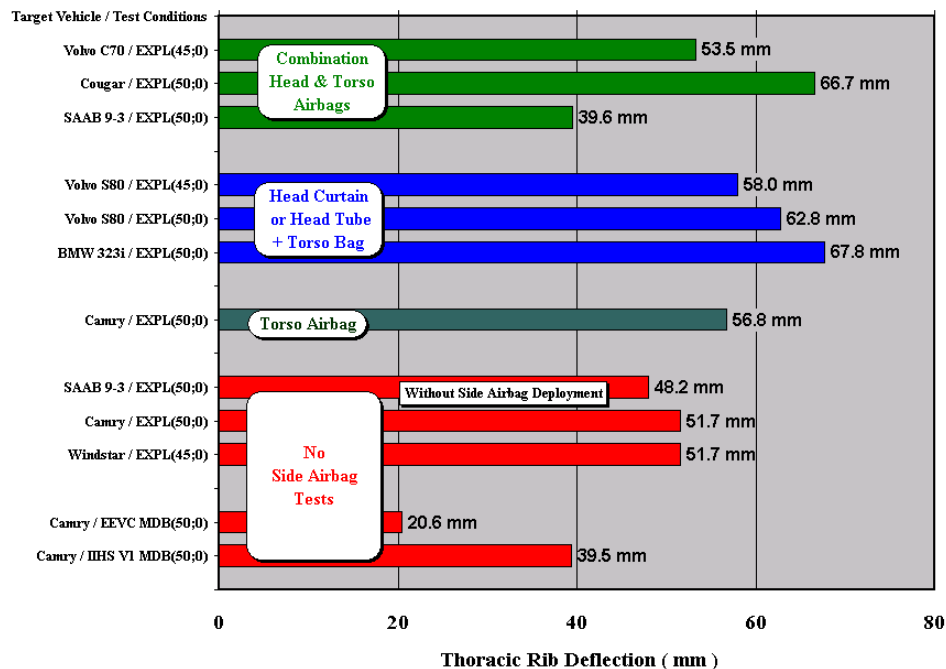

Figure 6. Driver Thoracic Rib Deflections Observed In Perpendicular Explorer and MDB Tests
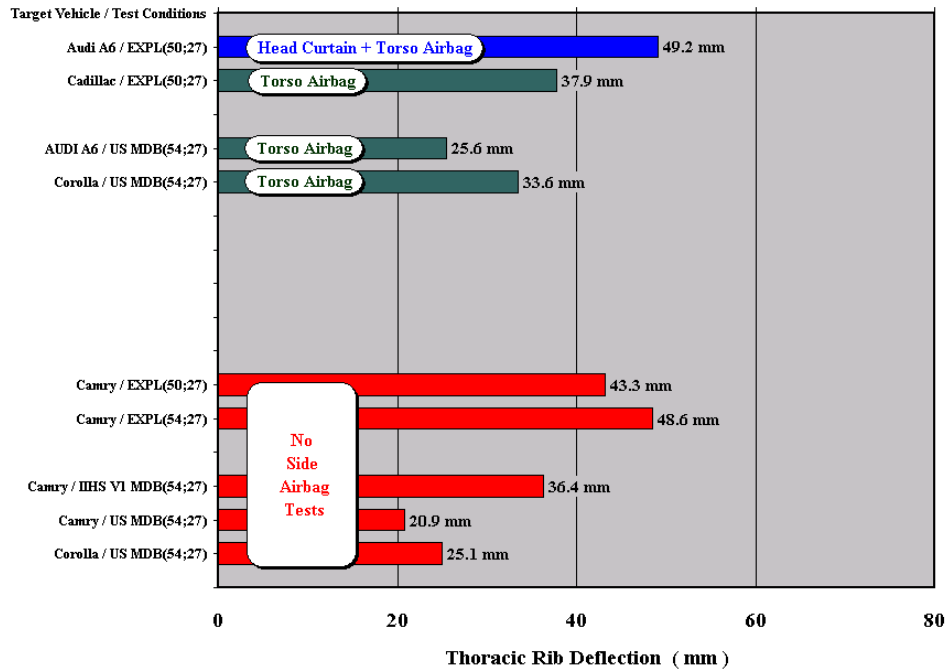
Figure 7. Driver Rib Deflections Observed In Crabbed Explorer and MDB Tests

As shown in Figure 7 it can be seen the peak driver thoracic deflection observed in the Toyota Camry test with the US MDB was 20.9 mm. The crabbed IIHS MBD test yielded a peak deflection value of 36.4 mm.

At face value, the overall results presented in Figures 6 and 7 would suggest that current side airbag systems afford no added benefit in terms of reduced thoracic injury risk. This is not exactly the case. Direct comparisons of the deflections observed across both the thoracic and abdominal rib elements, as a function of airbag deployment, for three paired vehicle tests are presented in Figures 9 through 11.

In the absence of a side airbag, one frequently observes large variations in the amount each rib element is compressed as the dummy interacts with

Figure 8. Influence of Crabbing on Thoracic Deflection Values

the intruding door structure. These variations are determined by the intrusion profile and localized stiffness differences. The intervention of a side airbag typically reduces the deflection gradient observed by virtue of the fact that the loading is now more distributed. The end result is a reduction in the level of compression experienced by those rib elements, which in the absence of the side airbag, would have been subjected to the greatest level of loading. However, the level of rib compression experienced by those rib elements, which in the absence of the side airbag, would have been subjected to the least level of loading, may be increased. Consequently, for the situation where, in the absence of a side airbag, the deflections are greatest in the abdominal region, intervention of a side airbag, may increase the level of compression observed in the thoracic region. This trade-off is illustrated in Figure 10 which depicts the driver rib deflections measured in the Toyota Camry, with and without airbag deployment, when impacted in the side by another Toyota Camry.

Collectively, the data presented in Figures 9 through 11, suggest side airbags afford a net benefit in terms of overall abdominal/thoracic injury risk reduction, but that the level of improvement is very modest in comparison to the potential head benefits.
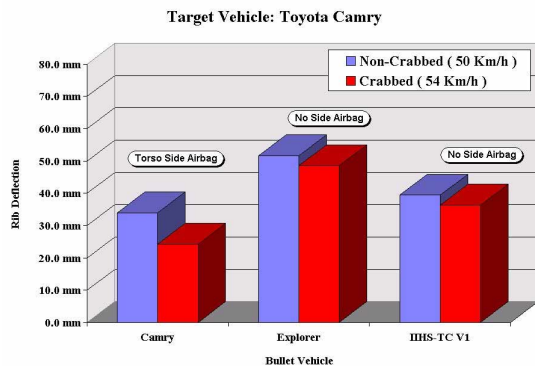
Target Vehicle : Toyota Corolla
Bullet Vehicle : US MDB (54 km/h; 27)

Figure 9. Rib Deflections - US MDB Tests.

Target Vehicle : Toyota Camry
Bullet Vehicle : Toyota Camry (50 km/h; 0)
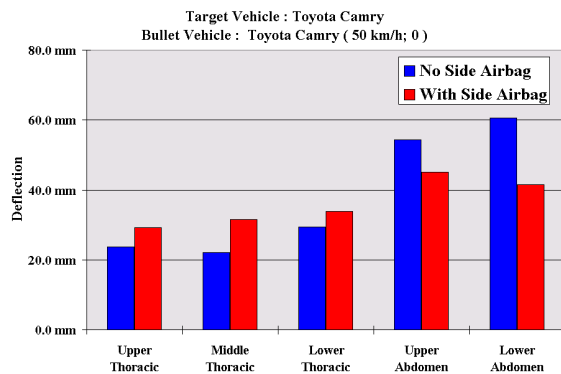
Figure 10. Rib Deflections - Camry Bullet Tests.

Target Vehicle : SAAB 9-3
Bullet Vehicle : Ford Explorer (50 km/h; 0)
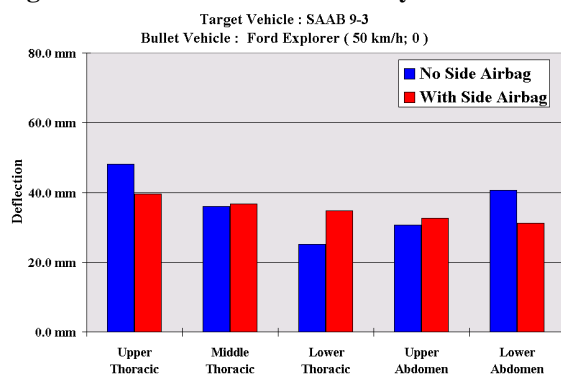
Figure 11. Rib Deflections Explorer Bullet Tests..

CASE STUDIES

Transport Canada's collision investigation teams have investigated a total of 72 collisions in which vehicles have been equipped with side air bag systems. In 44 of these crashes the side air bags were not deployed. For the 28 incidents where deployment of the side air bags did occur, there were adjacent occupants present in 24 cases. While, for the case vehicles, most of the latter crashes were side impacts, there were also 3 collisions which were essentially frontal, and one rollover event.

Most of the crashes were minor to moderate in nature and, in these, no more than minor injuries resulted. In particular, no significant air bag related injuries were noted.   One vehicle-vehicle crash resulted in 38 cm of crush to the driver's door, with fatal injuries to the elderly male occupant. Two collisions involving poles also resulted in fatal injuries; however, the localized crush measured 38 and 76 cm respectively, and the available torso side air bags were unable to mitigate the injuries sustained by the adjacent occupants.

The following cases studies describe some of the more severe collisions in the present series, plus a number of incidents of special interest because of the specific technology (e.g. head curtains) and/or the particular occupants involved.

SID3-1519 - A 1998 Audi A4 four-door sedan was travelling westbound along a one-way street, towards a traffic-light controlled intersection.   A northbound 1993 Acura Integra entered the intersection and the front of this vehicle impacted the left-front axle and driver's door of the Audi. Maximum crush to the Audi was 34 cm, located in the lower portion of the driver's door (10LYEW3).

The driver of the Audi was a 49-year-old male, 174 cm tall, with a mass of 77 kg. His seat was adjusted rearward of middle.   The driver was properly restrained by the available lap-torso seat belt, and the torso bag located in his seat back deployed in the crash. He complained of soreness to his neck, chest, and left leg, and of a headache. These symptoms were transient and the driver did not require any medical attention.

ASF2-1108 - A 1998 Volvo S70 four-door sedan commenced a left turn at a traffic-light controlled intersection as the light was changing from green to amber.   An on-coming 1997 Ford Escort continued into the intersection and the front of this vehicle struck the right-side doors of the Volvo (02RPEW3). A maximum crush of 30 cm was measured on the lower portion of the Volvo's right-front door.

There were four occupants in the Volvo: a 17-year-old female driver; a 19-year-old female right-front passenger; a 20-year-old male left-rear passenger; and a 19-year-old female right-rear passenger.   All of the occupants were fully restrained. Both front air bags, and the torso bag located in the back rest of the right-front passenger's seat, deployed as a result of the crash.

The driver and left-rear passenger were uninjured.   The right-front passenger sustained a sprained right ankle due to contact with the floor pan. The right-rear passenger suffered a fractured left

wrist as a result of contact with the right-front seat back.

SID3-1004 - A 1999 Mercedes E320 four-door sedan, travelling westbound along an urban road, came to a halt at a traffic-light-controlled intersection. When the light turned green, the driver commenced a left turn. A 1989 Pontiac Grand Am was travelling southbound. The driver of this vehicle failed to stop at the traffic light and the front of the Pontiac struck the right-side doors of the Mercedes (02RYEW3).

A maximum crush of 22 cm was measured at the rear edge of the right-rear door of the Mercedes. The torso bag, located in the right-front door, and the head curtain, located in the right roof side rail, both deployed as a result of the collision.

The fully-restrained, 67-year-old, male driver was 168 cm tall and of average build. He complained of pain to his neck and right-lower chest and did not require any treatment.

The right-front passenger, a 48-year-old female, was not belted. She was 161 cm in height and of small build. She sustained minor bruizing to her right leg from contact with the vehicle's side interior surface, and complained of pain to her neck and lower back.

The fully-restrained, right-rear passenger was a 41-year-old female, 169 cm tall, and of average build. She indicated that she had been struck by the rear trim panel as the head curtain deployed. Her right jaw was swollen with slight pain on palpation. She further complained of pain to her neck, right arm, and right leg.

SID3-1305 - The case vehicle, a 1995 Volvo 850 station wagon, was travelling westbound along a rural highway, approaching a four-way intersection. The roadways were covered in ice and were extremely slippery. The driver of a 1992 Ford Econoline ambulance, which was northbound on the intersecting roadway, was unable to bring his vehicle to halt at the stop sign. The front of the ambulance impacted the right-front axle and passenger's door of the Volvo (03RYAW3). The resulting maximum crush to the right-front door was 30 cm at mid-door level.

The right-front passenger was a 35-year-old female, with a height of 165 cm, and a mass of 62 kg. She was unrestrained with her seat in the fully rearward position. As a result of the collision, both the dashboard-mounted front air bag, and the torso bag located in the seat back rest, were deployed. The passenger sustained bilateral fractures to the pelvis as a result of interaction with the vehicle's intruding

side interior surface, and a laceration to the right side of her scalp from contacting the side window glass.

The driver, a 47-year-old male, was 170 cm in height with a mass of 87 kg. He was using the available lap-torso seat belt. The driver's front air bag deployed in the crash. He suffered a myocardial contusion and pneumomediastinum from contact by the air bag. He also sustained a depressed fracture of the left tibia, a fracture to the right fibula, and a contusion to the right leg, due to contact with the lower dashboard.

ASF2-1907 - The driver of a 1998 Lexus ES300 four-door sedan attempted to make a U-turn in the area of a T-intersection on a rural highway. The driver of a following vehicle, a 1989 Mercury Grand Marquis, was unable to avoid a collision and the front of this vehicle struck the left-side doors of the Lexus (09LDAW3). The maximum crush to the Lexus was 38 cm, measured on the left B-pillar at mid-door level.

Figure 12. 1998 Lexus ES300.

The driver of the Lexus was a 71-year-old male. He was 175 cm tall and had a mass of 90 kg. His seat was located in the mid-position of its fore and aft travel. The driver was fully restrained and both the front air bag and the torso bag, located in the back rest of the driver's seat, deployed in the crash. The driver sustained fatal injuries and expired en-route to hospital. No autopsy was performed. Notes from an external examination indicated that the driver's injuries included: a laceration and abrasion to the left side of the head from contact with the hood of the bullet vehicle; multiple, bilateral rib fractures; and multiple minor injuries to the chest, abdomen, and extremities due to interaction with the intruding side structure.

The driver was accompanied by a 74-year-old, female, right-front passenger. Her seat was in the mid-position of its adjustment range. The passenger was fully-restrained and her dashboard-mounted front air bag deployed. Following the crash, the passenger was unconscious. She was transported to

hospital where she was admitted for treatment. Her injuries included: fractures to the left pelvis and left arm due to contact with the centre console; a fractured seventh rib on the left side from seat-belt loading; plus multiple, minor contusions, lacerations and abrasions to the head and face, chest, and extremities.

ACR4-1929 - A 1999 Volkswagen Passat four-door sedan was northbound along an urban street. The driver was distracted by one of his child passengers and allowed the vehicle to mount the east curb. The right-front corner of the vehicle impacted a light standard, resulting in damage to the fender, wheel, and suspension components (12RFEW2).

The 71-year-old, male driver was accompanied by three children: a 12-year old female in the right-front seat; a 7-year-old female in the left-rear seat, and a 7-year-old male in the right-rear seat. All of these occupants were using the available lap-torso seat belt systems.

The right-front passenger's seat was adjusted to the rearward of middle position. Both front air bags, and the torso bag mounted in the right-front passenger's seat back, deployed in the collision. The right-front passenger sustained a bleeding nose as a result of contact with the front air bag. She received first aid from emergency medical services called to the scene but did not require any further treatment. None of the other occupants suffered any injuries.

ASF2-1028 - The driver of a 1999 Mercedes E320 four-door sedan lost directional control as his vehicle entered a curve in the road to the right. The vehicle entered into a clockwise rotation, crossed the centre line, and the vehicle's right-side wheels struck the curb. This contact tripped the vehicle which rolled onto its right roof side rail, and then onto its roof. The rear end of the vehicle struck a log lying on the ground and the vehicle came to rest.

Minor sheet metal damage resulted to the right-front fender, right sill, right-rear fender, roof and trunk lid (00RDAO1). The torso bag mounted in the right-front door, and the head curtain mounted in the right-side roof rail, deployed in the collision.

The driver, a 21-year-old male, was accompanied by a 21-year-old male passenger occupying the right-front seat. Both occupants were using the available lap-torso seat belts. Neither sustained any injury.

ASF2-1912 - A 1998 BMW 328i two-door convertible was travelling north along a limited-access arterial road. The driver attempted to leave the road, taking an exit ramp to the right, intending to travel eastbound. Both the driver and the passenger had been drinking earlier in the evening. The convertible was travelling considerably in excess of the 50 km/h advisory speed limit for the ramp, and the driver lost control in the right hand curve. The vehicle entered into a clockwise yaw, mounted the curb, and the left side of the vehicle struck a light standard. The pole broke away from its support. The convertible rolled over, the rollover protection system activated, and the vehicle came to rest upside down on top of the pole.

The pole came into direct contact with the driver's door (09LPEN5). The maximum crush was 76 cm, measured at the belt line, adjacent to the left-front door handle. The driver's door-mounted, torso bag was deployed in the collision, this being the only air bag in the vehicle which was activated.

The driver, a 37-year-old male, was 172 cm tall with a mass of 86 kg. Loading evidence on his seat belt system confirmed that he was fully restrained at the time of the crash. No vital signs were detected and the driver was declared dead at the scene. No autopsy was conducted. An external examination indicated that, due to contacts with the pole and left side vehicle interior, the driver had sustained a fractured neck; fractures to the left wrist and left pelvis; plus multiple contusions, lacerations, and abrasions to the face, chest, abdomen, and extremities.

The fully-restrained, right-front passenger was a 37-year-old male, 182 cm in height, with a mass of 86 kg. His seat was adjusted fully rearwards. The passenger received abrasions to the top of his scalp and right arm, probably due to contact with the ground, bilateral abrasions over the iliac crests from seat belt loading, and a contusion to the left arm.

ASF2-1914 - A 1998 Volkswagen Beetle two-door hatchback was travelling eastbound at high speed on an urban collector. As the vehicle approached an intersection with the entrance ramp to a highway, the driver lost directional control. The Volkswagen entered into a clockwise yaw and mounted the south curb of a large traffic island. The left side of the vehicle struck and broke away both a traffic sign and a large wooden utility pole. The vehicle continued down the road for 54 m before finally coming to rest.

The initial impact with the utility pole occurred just forward of the left-rear wheel. The pole pocketed in the vehicle's left side structure, driving the B-pillar forward and inboard (08LZAW3). The resulting maximum crush was estimated at 38 cm.

The fully-restrained driver was a 22-year-old male, 170 cm tall with a mass of 68 kg. His seat-mounted torso bag deployed; however, he received fatal injuries in the collision. A toxicological screen

indicated an elevated blood alcohol level and the presence of anti-depressant drugs. No autopsy was performed, the cause of death being reported as multiple blunt trauma.

ASF3-9624 - The case vehicle, a 2000 Infiniti G20t, was travelling westbound, in the passing lane of a four-lane, median-divided, urban arterial. The vehicle was overtaking a road sweeper when the driver of the truck attempted to change lanes. The left-front corner of the truck struck the right-rear corner of the Infiniti. This contact caused the car to rotate clockwise and mount the central median where the vehicle's left-side struck a light standard. There was direct damage to the left-front door, immediately ahead of the B-pillar, extending up from the door sill to the roof side rail (08LPAW3). The maximum penetration was measured as 43 cm.

Figure 13. 2000 Infiniti G20t.

The driver was a 48-year-old female, 163 cm tall, with a mass of 55 kg. She was fully restrained with her seat in the rearward of middle position. The combination head-thorax bag deployed from the back rest of the driver's seat. As a result of contact with the intruding side structure of the vehicle, the driver sustained fractures of the left superior-inferior pubic rami with slight displacement; non-displaced, bilateral, impacted fractures of the anterior sacrum; and a 0.5 cm laceration to the occiput.

DISCUSSION

The vehicle composition in North America has seen significant changes in recent years. The steadily increasing popularity of multi-purpose passenger vehicles in general, and sport utility vehicles in particular, can be expected to dramatically alter the nature and magnitude of the road safety problem. The height of the hoods of many of these vehicles coincides with the head of an occupant seated in a conventional passenger car, thereby exposing the car occupant to the potential of serious head injury in a side impact. The elevated ride heights of MPVs also expose the car occupant to

much greater risk of serious injury to the chest and abdomen in a side crash. Neither of these situations is currently addressed by existing side impact standards. While measures to control the aggressiveness of vehicles to other vehicles represent a possible long term approach to the objective of improving side impact safety, some short term interventions are also available.

Although initially developed to reduce head injury risk in side collisions with poles and trees, the present findings suggest that inflatable head protection technologies offer a potential means of greatly reducing the risk of head injury in MPV-to-car side impacts as well. The present findings, however, also indicate a number of design changes are required if the potential benefits are to be maximized. First, greater attention needs to be given to the design of side airbag cushions and tubes to ensure they accommodate the full range of occupant sizes and seating positions. Many of the systems tested in the present study provided very limited containment of the head over the full duration of the dummy loading sequence owing to the lack of width and/or height of the tube or cushion. Secondly, most of the side airbag systems were overpowered by the intruding front end structure of the SUV employed in the tests due to the amount of structural collapse of the B-pillar. From the testing performed to date it is clear that the upper limits of side impact protection will be defined by the ability to protect the chest and abdomen during the early portion of the side impact, and not by the ability to prevent head injury during the latter stages of the collision. Present technology appears very capable of accomplishing the latter. The former appears far more problematic. Reducing injury risk to the chest and abdomen in MPV-to-car side impacts will likely require significant changes in the design of the side structures to promote more near vertical intrusion profiles even when the load path is well above the height of the door sill.

What would constitute the most appropriate moving deformable barrier to promote and assess side impact protection from a regulatory standpoint has yet to be determined. As a minimum, it is clear that the geometry of a typical MPV needs to be more adequately represented, particularly with respect to hood height and ground clearance. A straight perpendicular impact appears preferable to a crabbed test from the standpoint of assessing driver head injury potential from hood contact. It also represents a more severe test of the front seat protection afforded by the side structure.

The initial results obtained with the prototype MDB developed by the IIHS are encouraging. The

intensity and timing of the head contacts produced with the barrier showed good agreement with those obtained in the vehicle-to-vehicle tests using the Explorer as the bullet vehicle. The thoracic responses obtained with the barrier were lower than those obtained in the Explorer tests. Nevertheless, they were of the order of magnitude of twice those obtained with current barriers used in regulatory testing. The lower thoracic responses, in part or in whole, may be attributed to the fact that the IIHS barrier was only ballasted to a mass of 1,500 kg rather than 2,160 kg, the approximate test mass of the Ford Explorer used in the vehicle-to-vehicle tests. The reduced mass was felt more appropriate since the objective of the current research effort was to identify test conditions and test parameters which could be reasonably expected to be met in the near term solely by means of improvements to the level of self-protection provided by impacted vehicles. Given the over-representation of the elderly in side impacts, it would appear desirable to limit chest and abdominal deflections, if based on the a small female dummy, to under 35 mm. To achieve this level of performance in a small passenger car when the striking vehicle is a mid-sized or large SUV and travelling at 50 km/h will almost certainly require complementary action to reduce the aggressiveness of the front-end structure of the striking vehicle. Opportunities to reduce the overall aggressiveness of striking vehicles will be explored in the next phase of Transport Canada's side research effort.

Clearly, additional field collision data on side-airbag systems are needed both to quantify their effectiveness and to fully understand their limitations. It is encouraging that, to date, no instances of serious injury directly attributable to the side airbag have been observed in Canada. Instances where injury severity may have been reduced have been observed.

ACKNOWLEDGMENTS

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